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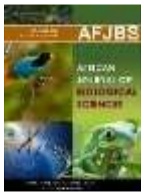

Assessment of Disease Incidence, Yield Loss, and Isolation of Soil Fungi from the Sorghum Fields in Anseba Region, Eritrea

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ABSTRACT

Sorghum (*Sorghum bicolor* L. Moench) is one of the world's five major cereal food plants along with maize, rice, barley, and wheat. Sorghum originated in North-East Africa and, it was domesticated for food production and is now grown extensively throughout the country. In Eritrea, several species and cultivars of sorghum are subjected to different diseases caused by various pathogens. There is no proper recorded data on diseases on sorghum and its intensity, hence, this survey with the objectives of- identifying the different diseases, assessing the inoculum of the soil, and its effect on the growth and yield of sorghum. The survey was carried out in three sub-zobas of the Anseba region such as Hamelmalo, Keren, and Elaberid from each of three sorghum-producing villages (*Mhabesh*, *Toronka, Eden, Megarh, Aribsari*, *Hamelmalo, Hntsats* and *Genfolom*) from July 2019 to November 2019. The diseases were noticed and the fungi were isolated from the sorghum-cultivated soils and infected parts of the plant. Anthracnose or red leaf spot (*Colletotrichum sps.)*, Rust (*Puccinia purpurea* Cke.), Grain smut *Sphacelotheca sorghi* (Lk.) Clint. or *Sporisorium sorghi.* The other saprophytic fungi also observed were *Alternaria*, *Aspergillus flavus*, *Aspergillus niger*, *Rhizopus, Mucor*, and the higher parasitic plant *Striga* were recorded. The highest percentage of disease incidence was recorded in Elaberid with 71.57% and the lowest was found in Hamelmalo with 61.54%. On the other hand, the lowest percentage of yield loss was found in Elaberid with 32.41%. The influence of epidemiological factors such as temperature, soil moisture, and rainfall showed that they could be some of the reasons for the development and spread of the mean disease incidence and yield loss (November) in 2019.

Keywords: *Sorghum Disease; Causal organisms; Disease incidence; Environmental factors; Yield loss.*

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is an African cereal crop that has been domesticating for about 6000 years. It is one of the five major cereal food plants globally, besides maize, rice, barley, and wheat. Despite its importance, sorghum production in Eritrea faces numerous challenges. These include biotic factors such as insect pests, diseases, weeds, and abiotic factors like erratic rainfall and drought. In Eritrea, sorghum is the most important and widely grown cereal crop, especially in the lowlands. It plays a crucial role in the national economy and diet, contributing around 45% of the total food production. (MoA, 2008). Sorghum production in Eritrea is low when compared with the output of other sorghum-producing countries in the world. However, the total production has been declining from year to year due to several biotic (insects, diseases, and weeds) and abiotic (erratic rainfall, drought, etc.) constraints (MoA, 2014).

Sorghum has been affected by artificial and natural climates (prolonged war, persistent drought, and different types of pest and disease attacks). Diseases caused by fungi (airborne/soil borne/seed-borne) on these crops are some of the major constraints that contribute to low production of the crops. Soil fungal population is favored largely by organic farming systems (Girvan et al., 2004). There are many constraints on sorghum cultivation due to several biotic (insects, diseases, and weeds) and abiotic (erratic rainfall, drought, etc.) factors. The effect of diseases on the crop results in yield loss by reducing the leaf number, plant height, and so on. Therefore, it is essential to survey the infections caused by different pathogens in various villages of Zoba Anseba and assess of inocula of the pathogens in sorghum soils.

Materials and Methodology

Site of the Survey: This survey was carried out in sorghum fields of three sub-zones (Elaberid, Keren, and Hamelmalo) of Anseba zoba from August to October 2019. Zoba Anseba is located at altitude 1280 m above sea level with 15° 55' 12.92'' N latitude and 38° 27' 46.9''E longitudes. This area receives an average annual rainfall of 459 mm and has sandy loam soil with PH of 6-7. The study area has an average temperature of 24 °C (MoA, 2005). From each sub-zoba (Elaberid, Keren, and Hamelmalo) three villages were selected during the survey. These were *Eden, Toronka*, and *Mehabesh* from subzone-Elaberid; *Ona, Megharhe*, and *Aribsari* from sub-zone -Keren; and *Gonfolom, Hntsats*, and *Hamelmalo* from subzone-Hamelmalo.

Sample Collection: In each village, the survey was conducted randomly (by diagonal random sampling) selected nine sorghum orchards, at monthly frequency for three months at different growing stages. The samples of infected leaves and the field soils were collected and brought to the plant Pathology Laboratory for assessment of disease, its percentage occurrence, and identification of causal organisms.

Isolation and Identification: All materials used in this experiment were sterilized using ethyl alcohol and boiled water except the sample leaves. Diseases were identified based on the symptoms observed on the part of the plant. Pathogens were identified by using identification keys (Gilman, 1957 Nagamani et al., 2006). Fungal identifications were carried out based on the characterization of symptoms and also examined under a compound microscope with 40X magnification power isolating the minute colonies and isolated from infected parts of plants (Aneja, 2004, Barnet and Hunter, 1972 Rifai, 1969). For the isolation of pathogens, the Soil Plate Method (SPM) (Warcup, 1950) and Serial Dilution Method (SDM) (Waksman, 1922) on PDA media were determined as per the standard methods (ISTA, 1985). Colony characteristic features of fungi were studied macroscopically by observing their growth which includes length and width, colour, the presence or absence of aerial mycelium, margin, wrinkles, and furrows as texture, and also observed microscopically (Diba et al., 2007).

Disease Incidence: The following formula is used for calculating the Disease Incidence (DI) (Jagtap et al., 2012):

$$\text{Percent Disease Incidence} = \frac{\text{number of plants infected}}{\text{total number of plant observed}} \text{ x } 100$$

Yield loss: The following formula is used to calculate yield loss (YL):

$$\text{Yield loss} = \text{yield of healthy} - \text{yield of infected}$$

Meteorological Data: Weather data were collected and recorded simultaneously from the metrological observatory available at Agricultural Research Centers, sub-zoba office (Figure 8).

Temperature: The average temperature in the Anseba zone extends from 5˚C to 45˚C. The highest temperature was recorded in June at 27.6˚C. On the other hand, the lowest temperature was recorded in January with 22.3˚C in 2019***.***

Rainfall: Based on our survey on Anseba zone the average recorded rainfall was from 0 mm in January to 190.2 mm in August**.**

Relative Humidity: the relative humidity was recorded between 66.7 to 79.2 percent.

Wind Speed: it was recorded as very low (40/km) in August whereas very high wind speed was in April i.e. 153.3/km.

Results and Discussion

During this survey, three diseases and a few disorders were observed on the sorghum crop in sub-zoba Keren, Hamelmalo, and Elaberid. Anthracnose is one of the fungal diseases caused by *Colletotrichum graminicola,* and it was found in all subzones of the Anseba region on leaves and stems of sorghum (Fig 1). The disease symptoms first appeared on the leaves as small tan to reddish-purple circular spots, which later enlarge and may unite to involve large areas of the leaf and the centers of the leaf spots fade to grayish-tan. Infection on the leaf midrib is particularly striking as it results in pronounced discoloration, consistent with observations reported by Singh (1998). *Colletotrichum graminicola* also causes a stalk rot and this disease usually follows the anthracnose stage on the leaves. The fungus enters the stalk directly through the rind or a wound of the rind and spreads to the inside of the plant. The lesions that form on the outside of diseased stalks usually have reddish to purplish margins and whitish centers. When infected stalks are split, the pith is red or purplish-red. Diseased stalks frequently break over at the base or a point one or more points above the ground. Poor head and seed development results from severe infections (Agrios, 2005).

Fig. 1 Anthracnose symptoms on stem and leaf of sorghum

Another disease, rust was documented in Hamelmalo, Keren, and Elaberid subzones on the leaves of sorghum, and this fungal is caused by *Puccinia purpurea*. The symptoms occurred on the crop at all stages of growth. The initial symptoms are small flecks on the lower leaves (purple, tan, or red depending upon the cultivar) (Fig 2). According to Wall (1992), pustules (uredosori) appear on both surfaces of the leaf as purplish spots which rupture to release reddish powdery masses of uredospores (Fig 3). Teliospores (Fig 4) develop later sometimes in the old uredosori or in telisori, which are darker and longer than the uredosori. The pustules may also occur on the leaf sheaths and the stalks of inflorescence (Agrios, 2005).

Fig. 2 Rust on sorghum leaves

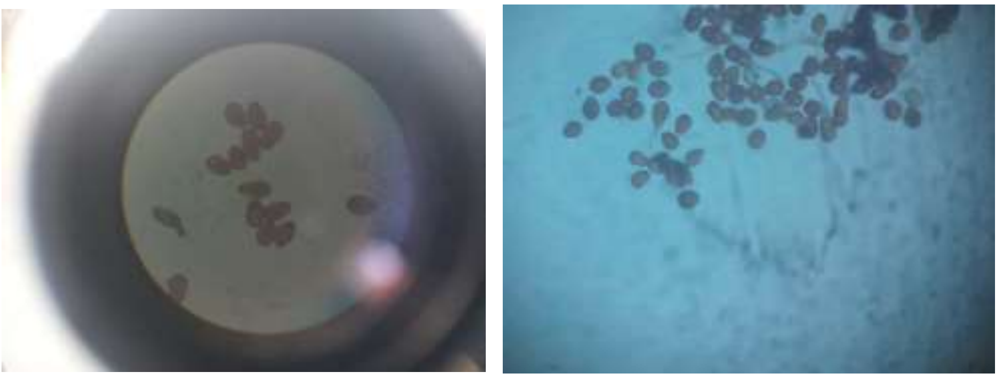

Fig. 3 Uredespores of Rust Fungi

Fig. 4 Teliospores of Rust Fungi

Smut Disease Symptoms appear on the infected grain that is covered with whitish to gray or brown or gray and brown striped smut spores and visible like cone-shaped galls or elongated sorghum seeds. As the disease progresses, the galls erupt and may infest other kernels. This result was supported by Frederiksen, (2000), Akpa, (1991), and Lynch, (1980) that smut is caused by various types of Fungi. Severe head infection during the reproductive and ripening stages usually results in economic losses (Fig. 5).

Fig. 5 Covered smut sori on the sorghum heads and smut spores (inset) from the kernels

Striga, a Phanerogamic Parasite, (*Striga asiatica* and *Striga densiflora)* weed was familiar in Hamelmalo and Keren sub zones. It is a partial root parasite and occurs mainly in the rain-fed sorghum. It is a small plant with bright green leaves and grows up to a height of 15-30 cm. The plants occur in clusters of 10-20/host plants. *S. asiatica* produces red to pink flowers while. *S. densiflora* produces white flowers. Each fruit contains minute seeds in abundance which survive in the soil for several years (Fig. 6). The genus *Striga* comprises about 50 to 60 species (Taye, 2013) and according to Esilaba et al., (2000), the emergence of *Striga* is positively associated with the extensive root system of sorghum.

Fig. 6 Striga in the Sorghum Field

Soil-Borne Fungi: Major fungal genera identified from Sorghum fields were *Alternaria*, *Aspergillus flavus, Aspergillus niger, Mucor,* and *Rhizopus (*Fig. 7*).* This result is in line with Syed et al., (2017), among the total of 7 different fungal species, the maximum colonies belong to Mucor (69) followed by *Aspergillus niger* (60), *Rhizopus* (59), *A. flavus* (57), *Fusarium oxysporum* (57), *Pythium* (20) and *Penicillium* (19) colonies were observed in Hamelmalo Sub Zoba.

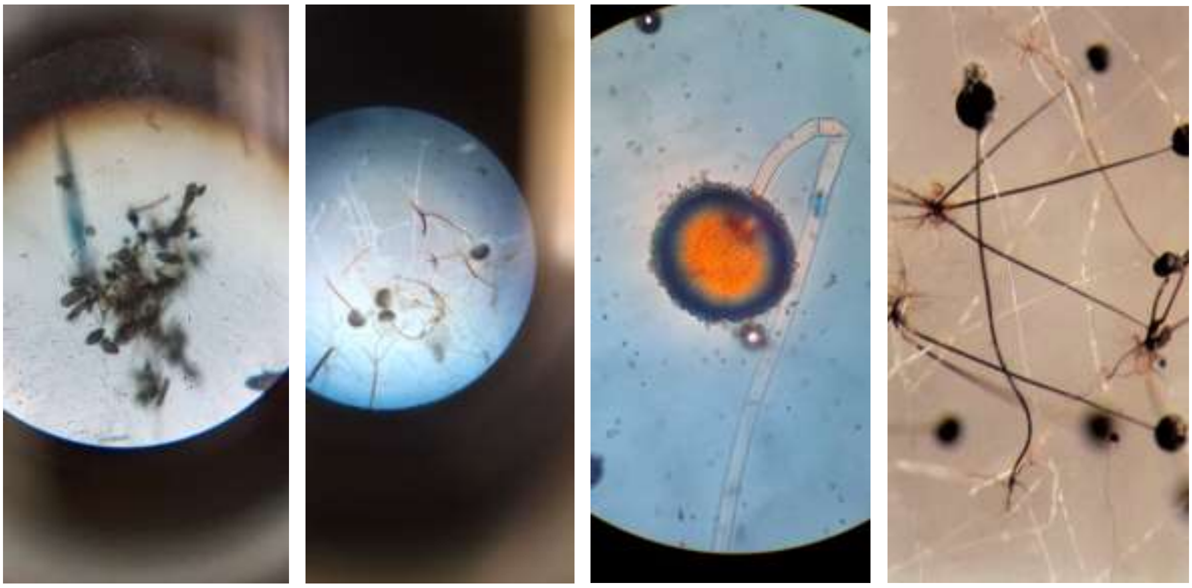

Fig. 7 Alternaria*, *Mucor, Aspergillus* sps., and *Rhizopus

Assessment of Diseases:

The highest percentage of disease incidence was recorded in the Elaberid sub-zone with 71.6%. On the other hand, the lowest percentage of disease incidence was found in the Hamelmalo sub-zone with 61.5%. During the time of growth, sudden changes in rainfall and wind speed played a major role in the dissemination of diseases. Also, the percentage of yield loss was noted, and the highest yield loss was in Keren with 36.7%, whereas, the lowest was in Elaberid with 32.4%. The maximum percentage of disease incidence was found in Elaberid which may be due to poor management practices. It was also noticed that the farmers are not aware of the different sorghum diseases and the factors (pathogens, environmental conditions, and host) that cause these diseases.

Growth and Percentage of Infection of Sorghum in Three Villages of Elaberid

In three villages of Elaberid, the highest disease incidence was in *Toronka* with 75.9% on the other hand, the lowest was in village 1 with 66.4%. The highest percentage of yield loss was in *Mehabesh* with 51.6% and the lowest yield loss was in *Eden* with 19.9%. The disease incidence gradually increased from the seedling stage to the flowering stage in all three villages, with the average DI being higher at the flowering stage. Before harvesting in September, rainfall decreased to about 60 mm, and wind speed returned to normal. It could be a reason for the production of grains, as a result, the yield loss was high in *Mehabesh* compared to *Eden*, but on average the YL is 32.41 percent was noticed (Table 1).

Table 1. Growth Parameters and Percentage of Infection of Sorghum in Three Villages of Elaberid

Growth and disease Parameters*	Phenology of Plant	*Mehabesh*	*Toronka*	*Eden*	Average
Plant Height (cm)	Seedling Stage	0.76	0.66	0.50	0.64
	Vegetative Stage	1.36	1.50	1.45	1.44
	Flowering Stage	1.79	1.88	2.67	2.11
Number of Leaves (average)	Seedling Stage	8.91	8.64	6.91	8.15
	Vegetative Stage	10.91	12.00	5.00	9.30
	Flowering Stage	13.18	14.09	7.27	11.52
Number of Infected Leaves	Seedling Stage	3.73	5.64	2.82	4.06
	Vegetative Stage	6.73	8.45	4.36	6.52
	Flowering Stage	12.64	13.00	6.45	10.70
Percentage of Disease Incidence	Seedling Stage	41.84	65.26	40.79	49.30
	Vegetative Stage	61.67	70.45	87.27	73.13
	Flowering Stage	95.86	92.26	88.75	92.29

* Plant height in centimeters and average no. of healthy and infected leaves.

Disease incidence in sorghum fields has been observed high during the vegetative and flowering stages. Various fungal pathogens, including *Alternaria, Aspergillus flavus*, *Aspergillus niger*, *Mucor*, and *Rhizopus*, have been identified as major culprits. This high incidence of diseases is a matter of serious concern for sorghum growers, as it directly translates into substantial yield losses, ranging from 20% to as much as 50% (Fig. 1). The vegetative stage is pivotal for the ultimate production of sorghum grains. During this stage, the plant establishes a robust root system, accumulates nutrients, and develops a strong photosynthetic apparatus. Any interruption or compromise in vegetative growth can have cascading effects on the subsequent reproductive phase, which directly influences grain formation.

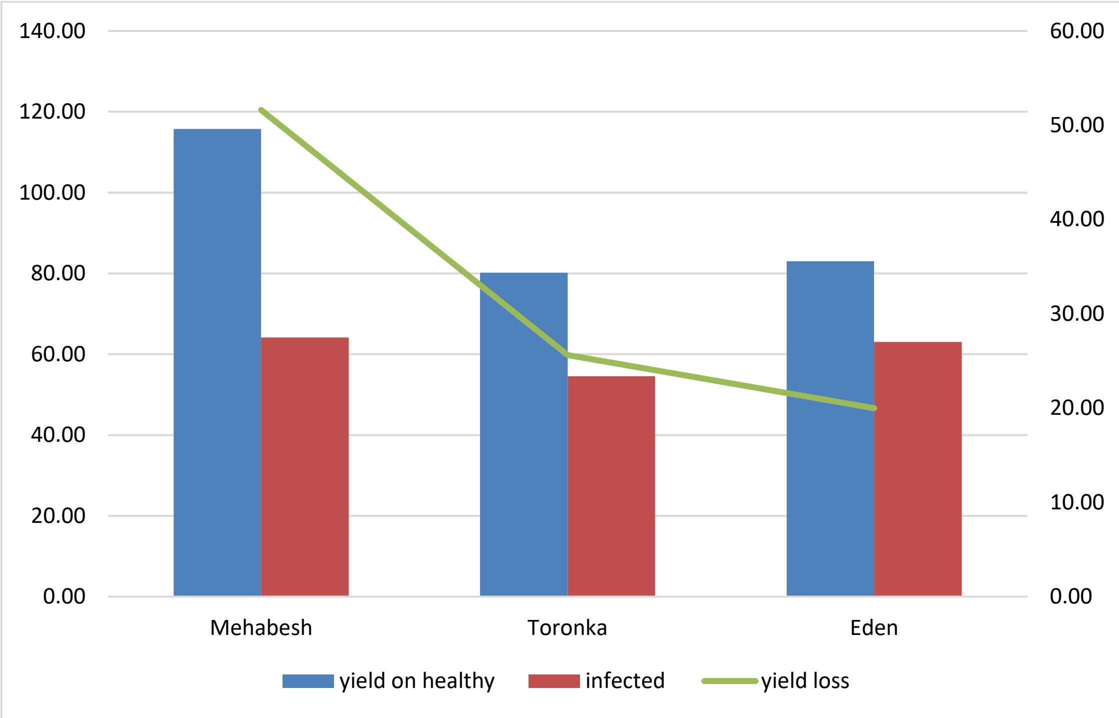

Fig. 1. Percentage of yield loss of sorghum in three villages of Elaberid

Growth and Percentage of Infection of Sorghum in Three Villages of Keren

The highest disease incidence was in *Ona* with 67.69 %. On the other hand, the lowest was in *Megharhe* with 53.5%. The highest percentage of yield loss was in *Aribsari* with 48.06 % whereas the lowest was in *Megharhe* with 29.13 %. The disease incidence progressively increased from the seedling stage to the flowering stage in all three villages. The average DI was shown more at the flowering stage. It is because the physiological development of the plant makes a platform for the pathogens' growth. The physiological development of sorghum plants plays a pivotal role in facilitating pathogen growth and colonization. The vegetative growth stage provides a nutrient-rich substrate and favorable conditions for pathogen establishment, while the flowering stage may weaken plant defenses, making it susceptible to pathogenic attacks. Understanding the interplay between plant physiology and pathogen dynamics is paramount for devising effective disease management strategies in sorghum agriculture. The yield loss was high in *Aribsari* compared to *Megharhe*, but on average the YL was 36.75 percent (Table 2).

Table 2. Growth Parameters and Percentage of Infection of Sorghum in Three Villages of Keren in Sub Zoba Anseba

Growth and disease Parameters*	Phenology of Plant	*Ona*	*Megharhe*	*Aribsari*	Average
Plant Height (cm)	Seedling Stage	0.40	0.52	0.52	0.48
	Vegetative Stage	1.03	1.58	1.66	1.42
	Flowering Stage	1.99	1.79	1.97	1.92
Number of Leaves (average)	Seedling Stage	10.36	8.64	6.55	8.52
	Vegetative Stage	12.18	11.09	10.82	11.36
	Flowering Stage	14.09	13.27	12.36	13.24
Number of Infected Leaves	Seedling Stage	1.09	1.09	1.09	1.09
	Vegetative Stage	11.27	7.36	9.73	9.45

	Flowering Stage	14.09	10.81	11.54	12.15
Percentage of Disease Incidence	Seedling Stage	10.53	12.63	16.67	13.27
	Vegetative Stage	92.54	66.39	89.92	82.95
	Flowering Stage	100.00	81.51	93.38	91.63

* Plant height in centimeters and an average of no. of leaves

The analysis of acquired data from the three villages of Keren, underscores the variation in disease impact on sorghum yield across the different growth stages. Especially, disease influence was most prominent during the vegetative stage and in the period leading up to flowering. These stages exhibited higher levels of yield loss due to the negative effects of disease incidence. The observed trend of heightened yield loss during the vegetative and pre-flowering stages aligns with existing knowledge of disease susceptibility patterns in crops. During these growth phases, the plants are more vulnerable to disease attacks due to their rapid growth, higher physiological activity, and limited energy allocation for defense mechanisms. This study elucidates the temporal patterns of disease impact on sorghum yield across various growth stages in Keren village (Fig. 2).

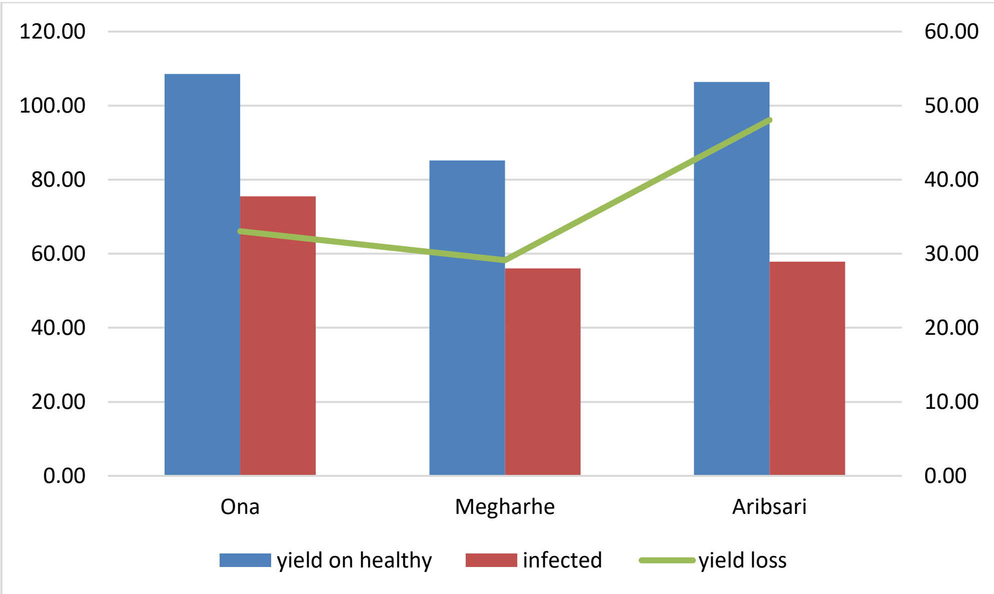

Fig. 2. Percentage of disease incidence and yield loss of sorghum in three villages of Keren

Growth and Percentage of Infection of Sorghum in Three Villages of Hamelmalo

Gonfolom exhibited the highest disease incidence at 73.1%, signifying a remarkable disease burden in that region. Conversely, Hamelmalo displayed the lowest disease incidence, recording 53.2%. Furthermore, Hamelmalo recorded the highest yield loss at 38.4%, whereas Village 2 exhibited the lowest yield loss at 30.7%. The spatial heterogeneity of disease incidence highlights the role of various factors, such as microclimatic conditions, plant genetics, and disease management practices, in shaping disease prevalence. The correlation between disease incidence and yield loss is evident, with higher disease incidence often associated with greater yield losses. The findings underscore the importance of location-specific disease management strategies to mitigate yield losses effectively (Table 3).

Table 3. Growth Parameters and Percentage of Infection of Sorghum in Three Villages of Hamelmalo in Sub Zoba Anseba

Growth and disease Parameters*	Phenology of Plant	*Gonfolom*	*Hntsats*	*Hamelmalo*	Average
Plant Height (cm)	Seedling Stage	0.78	0.39	0.65	0.61
	Vegetative Stage	1.83	0.98	1.99	1.60
	Flowering Stage	2.08	1.98	2.56	2.21
Number of Leaves (average)	Seedling Stage	9.64	8.09	9.36	9.03
	Vegetative Stage	10.00	10.36	10.36	10.24
	Flowering Stage	11.82	13.45	13.00	12.76
Number of Infected Leaves	Seedling Stage	4.36	1.18	1.91	2.48
	Vegetative Stage	7.73	7.00	4.36	6.36
	Flowering Stage	11.45	12.45	12.64	12.18
Percentage of Disease Incidence	Seedling Stage	45.28	14.61	20.39	26.76
	Vegetative Stage	77.27	67.54	42.11	62.31
	Flowering Stage	96.92	92.57	97.20	95.56

* Plant height in centimeters and an average of no. of leaves

The results consistently showed a gradual increase in disease incidence from the seedling stage to the flowering stage across all three villages. Remarkably, the flowering stage exhibited the highest average DI. Hamelmalo displayed a comparatively higher yield loss compared to Hntsats, with an average YL of 33.37 percent across all three villages. The observed temporal trend of increasing disease incidence aligns with known disease development patterns, where susceptible plants become more vulnerable to pathogens as they progress through their growth stages. The higher yield loss in Hamelmalo compared to Hntsats could be attributed to various factors, including variations in local environmental conditions, pathogen incidence, and agronomic practices (Fig. 3).

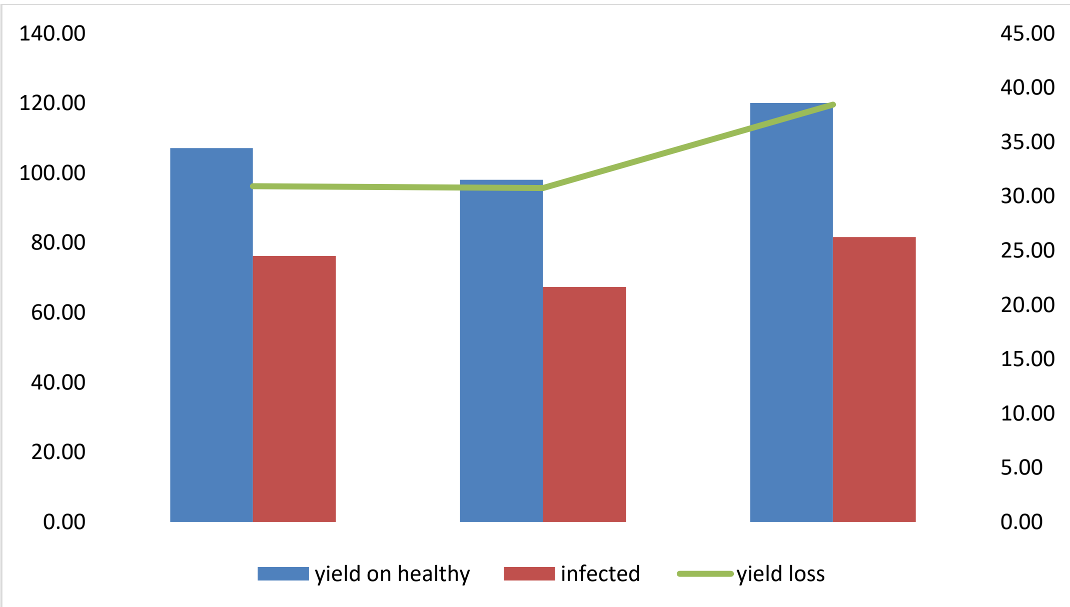

Fig. 3. Percentage of disease incidence and yield loss of sorghum in three villages of Hamelmalo

This analysis revealed distinct patterns in the meteorological condition during the study period. Maximum temperature peaked at 27.6°C, while minimum temperature stabilized at 22.3°C. Notably, August experienced a high maximum rainfall of 190.2 liters per hectare, while rainfall was minimal (0 liters per hectare) from January to March.

Relative humidity reached 79.2% in August and dropped to 66.7% in April. Relative humidity might be influenced, in such a way that they could be some of the reasons for to development and spread of the diseases in October 2019. Elevated relative humidity in August could have provided conducive conditions for the proliferation of moisture-dependent pathogens and might have impeded the development of certain fungal diseases. Temperature fluctuations likely impacted the rate of disease progression, affecting different phenological stages accordingly.

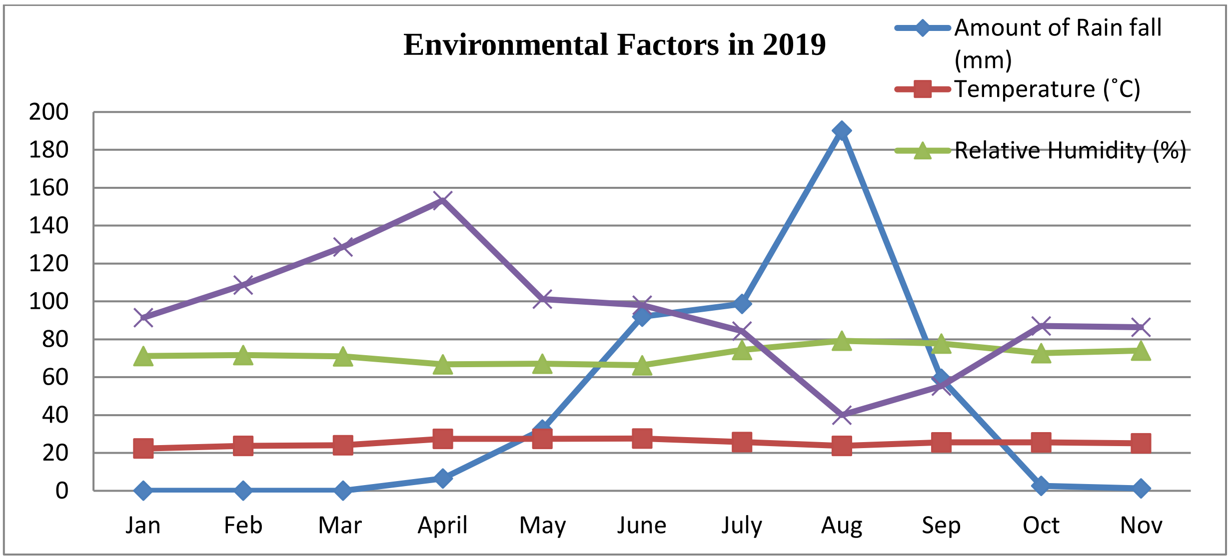

Figure 8: Environmental Factors (Rainfall, Temperature, Relative Humidity, and Wind Speed) in Anseba Zoba during the Year 2019

Conclusion

The present study concludes sorghum diseases and their intensity in the sub-zobas of Hamelmalo, Keren, and Elaberid. It was found that the highest percentage of disease incidence was recorded in Elaberid at 71.57%, while the lowest was in Hamelmalo at 61.54%. Some of the diseases were significantly influenced by variations in relative humidity and maximum temperatures, leading to an increase in both incidence and severity. The current situation underscores the importance of a thorough understanding of the disease triangle and the relationship between factors such as pathogen, host, and environmental conditions, including temperature, rainfall, and soil moisture. Without this knowledge, there is a risk of further infection and the spread of diseases to other areas, which could place sorghum production at greater risk in the country.

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